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Technical Assistance Program

Solid-State Lighting for Outdoor Municipal Applications

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OAK RIDGE NATIONAL LABORATORY
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1. Introduction

Solid-state lighting and *light-emitting diode* are terms that few municipalities would have recognized even ten years ago, yet today we find ourselves at the beginning of a municipal lighting revolution. We are seeing a swiftly growing category of new municipal lighting options, and their promise is substantial. The next generation of municipal lighting is positioned now to overcome the barriers between municipalities and their pursuit of better lighting options. Very long life, improved performance, design flexibility, and substantial energy savings are all now within reach with sensible adoption of LED technology.[1]

Although LED lighting presents new opportunities for municipalities to improve their existing lighting, several considerations are advisable for those making their first forays into solid-state lighting. Among the questions a municipality should consider are:

- What are the basics of LED lighting?
- Can I trust what vendors claim about their products?
- How can I be sure my project is cost-effective?
- What resources are available to help us with our project?

Some municipalities are in a position to hire outside consultants to assist with the lighting design of a project. Others have sufficient in-house expertise to specify the lighting products that fulfill specific project needs. This guide is tailored to municipalities that might not have sufficient experience with this technology. The purpose of this guide is to provide sufficient information about outdoor LED lighting, so that municipalities are in a position to make informed decisions about the options under consideration.

This guide contains an introduction to the basics of LED technology, illustrating how LEDs work and how LED performance has evolved to the point at which it is now a reliable alternative to many existing lighting methods. This guide also explains the benefits and challenges of working with LEDs, and it examines the lighting applications that are most suitable for municipalities, given the current state of the technology.

The guide also helps municipalities understand how to evaluate and verify LED performance. It lists representative programs and standards for ease in selecting high-quality LED products. In cases where these standards do not yet exist, the guide provides strategies for extracting important information on the performance of an LED product from laboratory data. The guide indicates how to evaluate the veracity of a manufacturer's claims, so that municipalities can minimize risk to their investments in solid-state lighting.

Finally, this guide focuses on product warranties, opportunities for purchase incentives, and how to conduct an economic analysis of a lighting project. A resource list completes this guide.

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[1] *LED* and *SSL* are typically used interchangeably in lighting parlance; this document will primarily use *LED* for the sake of consistency.

2. LED Basics

2.1 Solid-state Lighting: A Primer

Solid-state lighting (SSL) is a technology typically referring to light-emitting diodes (LEDs) for delivering light. A diode is an electronic device that limits the flow of electric current to one direction, and an LED is a specialized type of diode that uses semiconductor material to emit large numbers of photons when this current is passed through it (also producing heat as a by-product).[2] The light produced by an LED shines outward through a plastic lens that surrounds the LED chip itself. The back side of the LED frequently contains heat sinking elements to dissipate the heat given off by the diode.

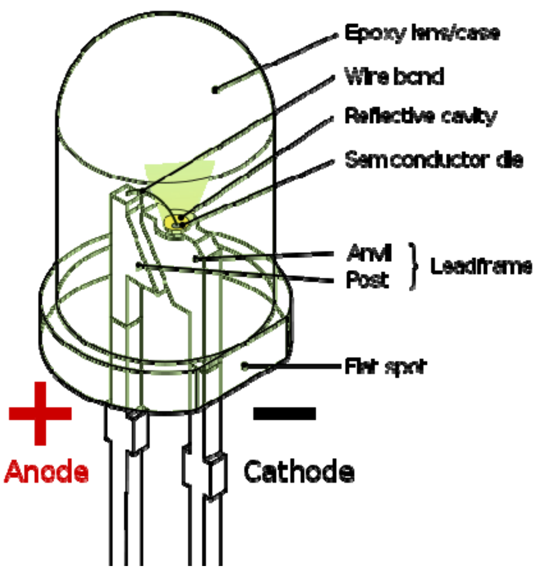


Figure 2.1a. Diagram of a light-emitting diode

LEDs are not a new technology. In fact, the first practical LED was created approximately fifty years ago. Since that time, LEDs have steadily evolved into a practical solution for many high-brightness, white-light applications.

The following figures demonstrate the advancements LEDs have made in lighting efficacy in recent history. Lighting "efficacy" is expressed in lumens per watt, which is the measure of the amount of light delivered for every watt of power used by a light source—essentially, efficacy is the "bang for the buck" when it comes to lighting performance.

Evolution of the light-emitting diode

Across the past fifty years, LEDs have improved to become brighter, more efficient, and highly versatile.

The first generation of LEDs saw little practical application beyond indicator lights, where they are still used today in many devices.

LEDs eventually became popular for low-light, color applications such as advertising signage and effect lighting.

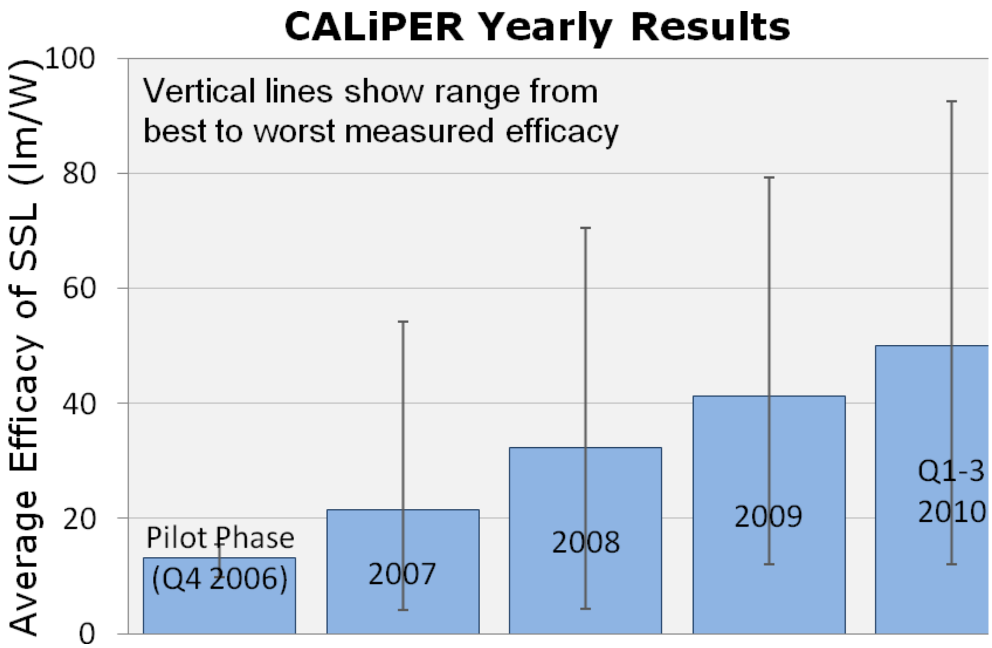
Within the past decade, white light has become a possibility with LEDs, ushering in many new lighting possibilities.

In the near future, the performance of LED products will surpass that of most other lighting technologies, with electronic controls systems offering high degrees of design flexibility.

Sources (top to bottom): Cleanparts.com, LED Open Sign, US DOE, Shanghai Yongji Co., Ltd.

[2] This phenomenon is called *electroluminescence.*

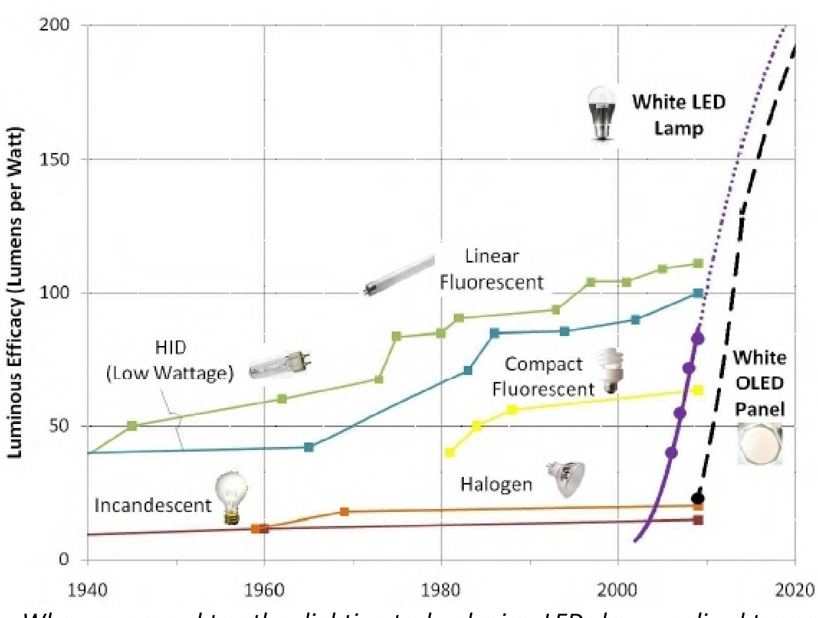
Figure 2.1b. Recent improvements in commercial LED product efficacy



The U.S. Dept. of Energy's CALiPER program assesses real-world performance of commercially available LED products. This chart illustrates how the average efficacy of tested LED products has tripled in the span of just the past few years.

Source: CALiPER Summary Report, Round 11, 2010

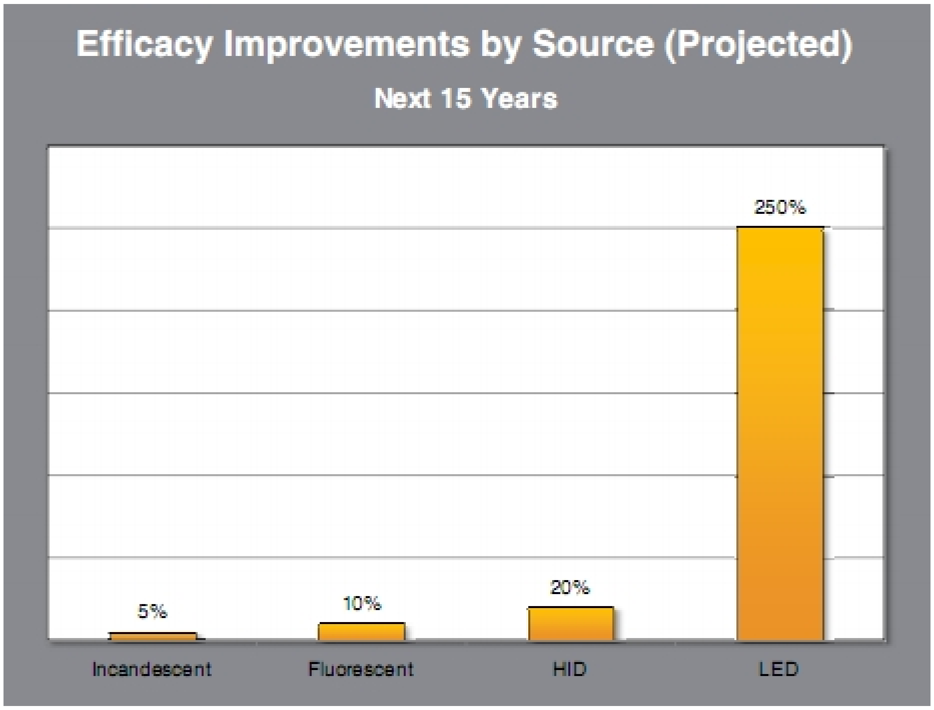
Figure 2.1c. Historical and predicted efficacy of various light sources



When compared to other lighting technologies, LEDs have realized tremendous performance improvements in a very short time. The maximum theoretical efficacy of LEDs surpasses every other existing light source.

Source: Navigant Consulting, Inc – Updated Lumiled's chart with data from product catalogues and press releases

Figure 2.1d. The future promise of LED efficacy



Although the room for future improvement in efficacy has tapered off for most incumbent sources of light, LEDs possess great potential for continued improvement.

Source: DOE SSL Multiyear Plan 2009; NIST

LEDs for general illumination applications are still considered an emerging technology. With each successive generation of products continuous improvements have occurred in light output, length of lifetime, and design flexibility. The lighting landscape has shifted with each successive generation of LED products, too; the current generation of luminaires exhibit both promise and problems. An assessment of the current strengths and weaknesses of this technology is provided below.

Benefits of LEDs

- **Energy efficiency** – Many high-quality LED fixtures are now competing effectively with existing technologies in converting electricity into visible light, rather than into heat. In this context, current LEDs are approximately five times as efficient as incandescent lighting, and can deliver comparable performance to metal halide or high-pressure sodium lighting with lower power use. The efficiency of LED luminaires has steadily improved over time.

- **Long life** – The lifetime of LEDs compare very favorably with most of the other current lighting technologies. Claims of up to 50,000 hours of lifetime operation are common for SSL. Depending on the amount of daily use, these claims will often translate into a decade or more of operation. To the extent that the claims are reasonably accurate, this long lifetime is a noteworthy consideration for

Drawbacks of LEDs

- **Product cost** – In most lighting scenarios the LED option is significantly more expensive than incumbent technologies. Although LED luminaires pay a return on this investment over time through lower energy bills, the higher up-front costs can be a challenge for some municipalities that are unable to budget far in advance for lighting upgrades.

- **Variable product quality & performance** – Because solid-state lighting as a general illumination source is still relatively new, product performance is variable. Further, manufacturer claims about performance are typically not verified and might be overstated. This can make evaluating product quality more of a challenge for municipalities. Until additional standards are developed and more field experience is gained, municipalities cannot be guaranteed that LED adoption is risk-free, compared to incumbent lighting technologies.

lighting applications that are difficult or expensive to maintain.

- **Directional light** – LED lighting is directional by nature, making it easier to place light exactly where it is desired. As a result, light pollution—excessive or obtrusive artificial light—can be reduced with LEDs. This technology can also reduce overall light levels at a site while still covering the essential areas with adequate light.

- **Other benefits** – SSL products are often well suited for integration with electronic controls such as timers, dimmers, and occupancy sensors that enable additional energy savings. LEDs offer improvements over older lighting technologies in resisting vibration, operating in cold temperatures, compactness, instant strike and re-strike, and minimal ultraviolet light.

- **Product support** – The very long life of SSL products leaves some concern as to whether current products can be serviced across their lifetimes, or whether they can be replaced in case of early failure. With many new manufacturers competing in the SSL arena, it can be difficult to predict which ones will be around when support is needed.

- **Learning curve** – LEDs introduce new lighting capabilities, and in turn, new technical considerations. Integrating LEDs into municipal lighting plans might require lighting or maintenance staff to absorb new information on working with LED luminaires. Lighting designers involved in such projects might also need to understand a new set of performance metrics and design considerations.

2.2 Outdoor Applications for Municipalities

Deciding whether LEDs make sense for a municipal application depends on the current strengths of LED technology for that application. Some applications will require additional advancements in this technology or luminaire design before they become feasible. The list of applications for which creditable LED products exist is growing rapidly. Several outdoor applications for municipalities are good points of entry into solid-state lighting:

Figure 2.2. Feasible LED applications for outdoor municipal settings

Traffic and pedestrian signals

With constant operation and because of the colored light requirements, this application is seeing widespread penetration of LED products.

Street lighting

Street lamps are present in large numbers in municipal settings. The high cost and inconvenience of street light maintenance make LEDs a worthwhile consideration in many cases.

Parking lot lighting

LED lighting is worth considering for some parking lot lighting scenarios, for many of the same reasons as street lighting.

Parking structures

The need for 24 / 7 security in parking structures translates into a significant energy savings opportunity.

Lamp post / decorative fixtures

LEDs are well-suited for the low pole heights of lamp post fixtures, and can be designed to minimize light pollution.

Wall packs

Long hours of operation and a need for directional light make exterior wall packs an appealing application for LED luminaires.

Safety Lighting

LED lighting is a good solution for many safety lighting scenarios where low-light levels are desirable, including hand rails, path lighting, step lights, and bollards.

Effect Lighting

LEDs offer design flexibility suitable for many aesthetic applications such as accent lighting or color-changing applications.

Sources (L-R): CEIEC Jiangsu Corporation, US DOE, BetaLED, Cree, Inc., Cree, Inc., Lumecon, Cooper Lighting, 3G Lighting Inc.

2.3 The Right Time to Adopt LED Technology

As with any emerging technology that promises to deliver higher performance at a lower price in the future, the question is inevitably raised: *Should we adopt now, or wait?* There is no straightforward answer to this question with regard to LEDs. It is true that the cost of LED products is relatively high compared to existing technologies, and these costs will come down in the future. It's also easy to see that although the performance of SSL fixtures has been improving steadily over recent years, even better LED products will be developed in the foreseeable future.

However, municipalities that wait for the "perfect time" to convert to LED lighting might find themselves waiting indefinitely, as there will always be better options on the horizon. LED lighting offers lighting performance and energy-saving benefits immediately, and so a decision to adopt the technology can confidently be made if an appropriate economic (cost-benefit) analysis is performed. The following considerations might assist in such an analysis:

At present, SSL appears to be a better choice for lighting installations in new construction, in existing applications where the installed lighting performs poorly and is due for replacement, or for existing lighting applications where maintenance or energy costs are quite high. In these scenarios, the higher up-front cost of

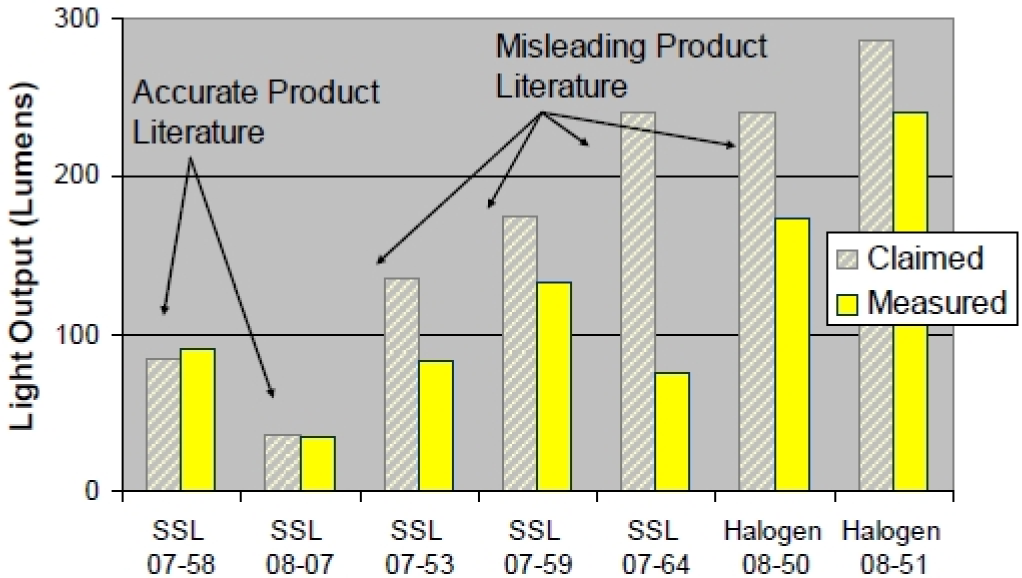
LED product might be mitigated by an attractive return on investment through savings on energy costs or maintenance.

Municipalities without adequate resources for LED projects, or whose incumbent technology is sufficient at the moment, might consider holding off on adopting LEDs until costs go down, or performance goes up. It might still be a good idea for municipalities in this position to try small LED projects. By “testing the waters” with LED projects on a small scale, municipalities might be in a better position to implement LED lighting broadly when they feel their time is right.

2.4 LED Performance: Separating Truth from Fiction

As with the claims of many commercial products, the claims of LED manufacturers should be carefully considered, especially because the marketplace is burgeoning and competition is increasing.

Figure 2.4a. Manufacturer claims versus actual performance[3]



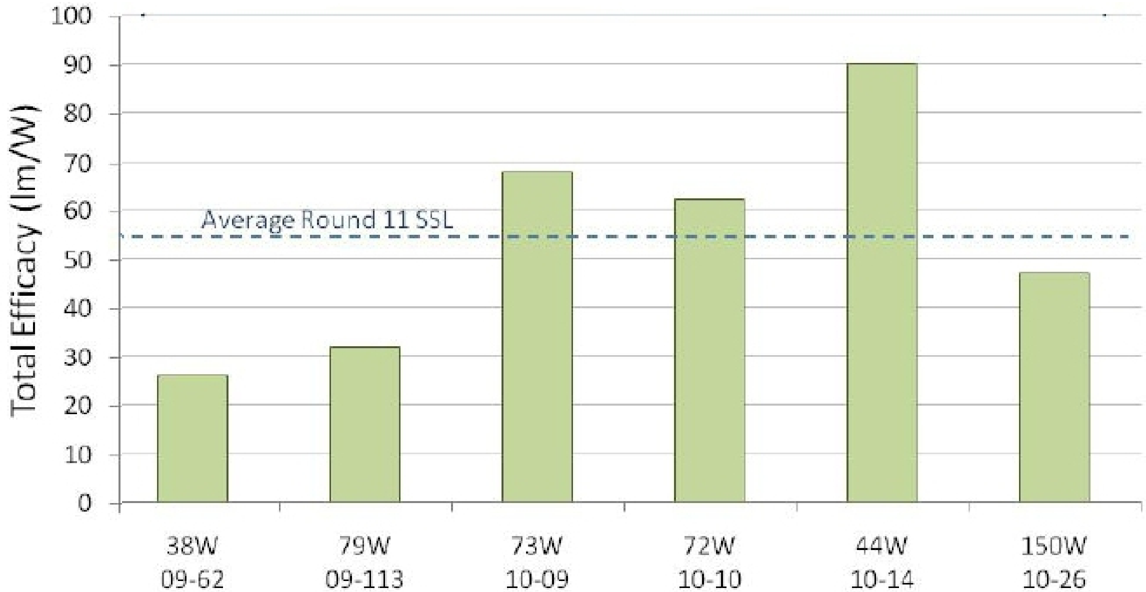
This chart shows that there may sometimes be a large difference between a manufacturer’s claims, and the actual performance of their luminaire.

Source: CALiPER Summary Report, Round 5, 2008

The U.S. Department of Energy’s (DOE) testing of commercially available LED products (through the CALiPER program) has found that only about one-third of products tested were found to have accurate performance claims. Exaggerated claims on product performance are nothing new and not uncommon. With the relatively high material costs of LED products, financial risk should be a significant consideration. Aside from financial risk, the hazards of possibly selecting an underperforming product can be especially significant for first-time adopters of LED lighting. A poor initial experience with an LED product will not likely lead to future adoption of the technology; and city officials and residents might be resistant to a municipality’s future attempts to use the technology if early results are disappointing.

[3] The products indicated here are for an interior lighting application; this graph is purely illustrative.

Figure 2.4b. Variation in performance among tested LED Products



In this sampling of LED luminaires, note the wide variation in efficacy performance. With evolving technologies like SSL, large performance discrepancies can occur among different products.

Source: CALiPER Summary Report, Round 11, 2010

What this all means for municipalities shifting toward LED lighting is that special care must be taken in selecting vendors and products. The following section provides guidance on maximizing the benefits of LED projects under consideration by municipalities.

3. Selecting the Right LED Product

3.1 Shortcuts to Identifying High Quality

Although LEDs are considered an emerging technology, standards have already been established that can help users select high-quality lighting products with a greater degree of confidence. Two notable programs that have placed an emphasis on LED products are the DesignLights Consortium, and the ENERGY STAR® program. Both have sought to establish minimum specifications for LED luminaire performance, and require laboratory tests to qualify products for recognition. Most of the luminaire categories covered by ENERGY STAR are related to indoor applications, whereas the DesignLights Consortium focuses on outdoor municipal lighting. The outdoor applications covered by the DesignLights Qualified Products List include:

- Pole / arm-mounted area and roadway luminaires
- Pole / arm-mounted decorative luminaires
- Wall-mounted area luminaires
- Parking garage luminaires
- Fuel pump canopy
- Outdoor retrofit kits[4]

[4] Specification currently in development

Both the DesignLights Consortium and ENERGY STAR websites provide lists of products that have qualified under their respective specifications.[5]

Other efforts take a more holistic approach to guiding consumers on LED installations, providing broader project specifications for LED projects. These efforts are based on application performance, whereas DesignLights and ENERGY STAR qualifications are based on equipment performance. The Illuminating Engineering Society has published recommended practice guidelines for lighting design. The DOE's Commercial Building Energy Alliances (CBEA) has developed multiple LED project specifications, including the common municipal applications of parking lots and parking garages.[6]

Similarly, the DOE's Municipal Solid-State Street Lighting Consortium (MSSLC) is in the final stages of drafting a model municipal specification for municipal LED roadway lighting.[7] This specification will offer a customizable template for municipalities to streamline LED roadway lighting applications by providing a clearer understanding of how well a proposed LED project will meet the standards of a high-quality installation.[8]

Although the intent of each of these programs and collaborations is to identify high-quality products or installations, these specifications cover only *general* performance standards for *typical applications*. The specific needs of any LED project might warrant further scrutiny for performance characteristics not covered by these specifications.

The absence of a particular product from a qualified products listing should not necessarily eliminate that product from consideration. For example, an applicable specification category for the product type in question might not yet exist. Or the product might still be under testing, or perhaps the manufacturer is not aware of the specification. A manufacturer should be contacted for information about why a promising product for a municipal application has not obtained a relevant qualification. It is possible that unqualified luminaires might still perform to a high standard, but it is prudent to determine whether the lack of qualification is a sufficient reason not to purchase the product. The next section of this guide is dedicated to helping municipalities assess LED products that have not attained a qualification standard, but have been subjected to creditable laboratory testing.

3.2 The LM-79 Report

In many aspects of LED performance, the characteristics of the individual LEDs cannot be used to accurately predict the performance of the LED luminaire as a whole. Light distribution and thermal management, for example, relate directly to the overall design of the integrated product. Two luminaires containing the exact same LED chips could perform quite differently because of differences in the design of the luminaire. A laboratory testing method, LM-79, assesses how an integrated LED luminaire performs.

The LM-79 was developed by the Illumination Engineering Society of North America (IESNA, or more commonly, IES) as a testing procedure for LED luminaires with integrated controlling electronics, heat sink(s), and fixture. Luminaires tested under LM-79 should be fully integrated and require nothing more than incoming voltage in order to function. IES LM-79-08 (commonly referred to as LM-79) reports contain very

[5] Visit http://www.designlights.org/solidstate.about.php and http://www.energystar.gov/index.cfm?fuseaction=find_a_product for more information.

[6] More information may be found at http://www1.eere.energy.gov/buildings/alliances/technologies.html

[7] Track progress on the specification at http://www2.eere.energy.gov/buildings/ssl/resources.html

[8] More information on this specification will soon be provided at http://www1.eere.energy.gov/buildings/ssl/consortium.html

useful and accessible performance data on LED-based lighting products.[9] It is important to note that the procedure simply records impartial luminaire performance data, and an LM-79 report should not be considered a "seal of approval" or certification.

Figure 3.2a: Key Luminaire Performance Data from Sample LM-79 Report

```
LAMPS: FORTY-EIGHT WHITE MULTI-CHIP LIGHT EMITTING DIODES (LEDS),
       TILTED 30-DEGREES FROM VERTICAL BASE-UP POSITION.
TOTAL INPUT WATTS = 52.5 AT 120.0 VOLTS, 0.441 AMPS
LED DRIVER: [redacted]
NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT
      VOLTAGE (120VAC, 60Hz) TO THE LED DRIVER. LED DRIVER INFORMATION
      PROVIDED BY CLIENT.
TOTAL LUMEN OUTPUT: 3872
COLOR TEMPERATURE AS MEASURED IN INTEGRATING SPHERE TEST # ITL65951: 4947K
COLOR RENDERING INDEX AS MEASURED IN INTEGRATING SPHERE TEST # ITL65951: 67
LED DC DRIVE CURRENT (mA): 350 (PROVIDED BY CLIENT)
POWER FACTOR: 99.2
BUG RATING: B1 U1 G1
LUMINAIRE EFFICACY: 73.8 Lm/W
CLASSIFICATION: Short, Type II
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Source: Independent Testing Laboratories, Inc.

A luminaire that has been tested under the LM-79 method receives a corresponding, detailed report. Although different LM-79 reports might vary in the specific information they contain, or the way in which this information is presented, all LM-79 reports contain information related to several fundamental aspects of luminaire performance, detailed below.

3.2.1 Light Characteristics

The amount of light produced by an LED source, and how it is distributed, are both crucial in determining whether a product will provide the proper light intensity and distribution for a lighting application. In municipal settings this is especially important because both of these factors relate directly to issues of safety and security. Light sources with low lighting levels can create lighting conditions that are unsafe for pedestrians and drivers. On the other hand, excessive light levels might create disabling or uncomfortable glare for users, and exacerbate light pollution issues. Uniformity of light is important so that the lighting design minimizes both shadows and "hot spots" (areas of high light intensity), in favor of more even light levels across the site.

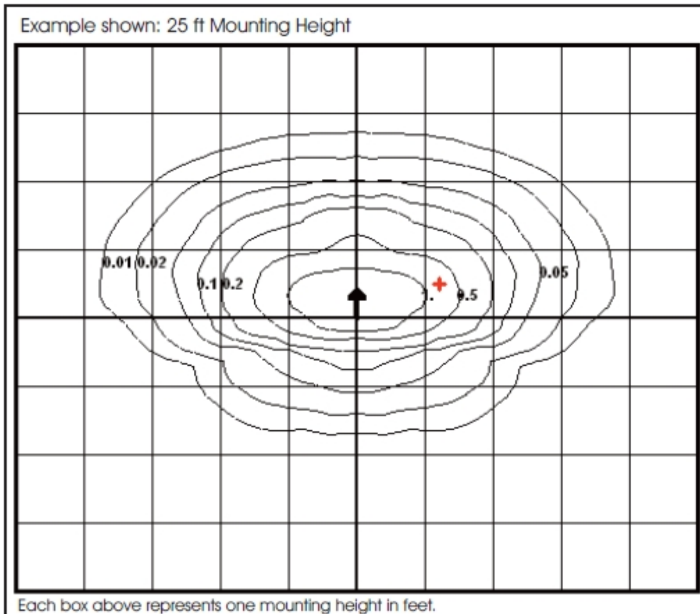
The LM-79 addresses these concerns by presenting essential information on an LED luminaire's light profile. The report expresses the total light output (expressed in lumens), and can provide information about how the total light produced by a luminaire compares with other sources.[10]

It is also typical for the LM-79 to contain information relating to the light distribution of a luminaire, shown through luminous intensity. Although this information is one of the more challenging aspects of the LM-79 to interpret, it helps in consideration of how a particular luminaire will illuminate a space, given its light

[9] A sample LM-79 report can be viewed at http://www.lightingfacts.com/Downloads/Generic_LM79_Report.pdf
[10] However, later in this section we will demonstrate how a well-designed LED luminaire might, in some cases, produce appropriate illumination with less total light output than that from traditional light sources.

distribution. The luminous intensity of a luminaire goes beyond simply expressing the total amount of light produced by showing how much light falls within certain angles of orientation. It is useful to think of a light source's light distribution as its lighting "footprint." The illustrations below show two ways in which an LM-79 report might convey information on a luminaire's light distribution.

Figure 3.2b. Sample isoilluminance plot for an LED luminaire



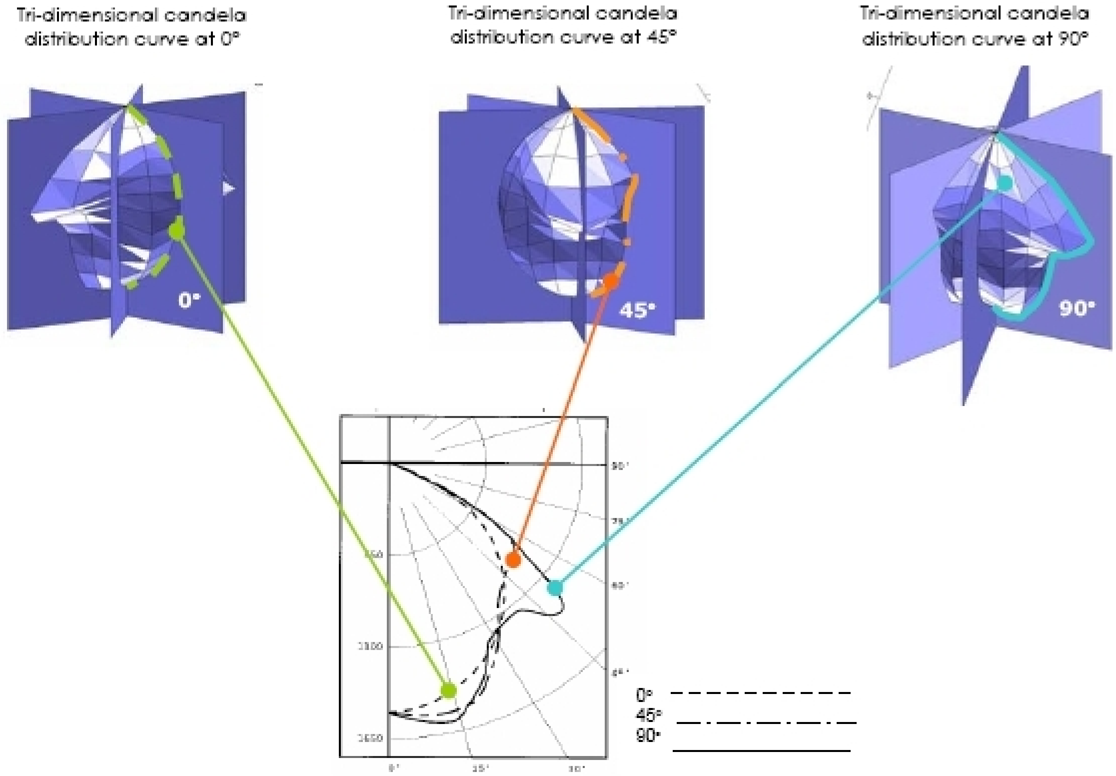
Mounting Height (ft)	Multiplier
10	6.250
15	2.778
20	1.563
25	1.000
30	0.694
35	0.510
40	0.391
45	0.309
50	0.250

+ = Point of max candela

This isoilluminance chart provides a bird's eye view of a product's light footprint through contour lines. The intensity of light within each contour ring, as well as the dimensions of each ring, may be scaled to fit a fixture's mounting height.

Source: US DOE, *Walking Through Examples of Real LM-79 & LM-80 Reports*

Figure 3.2c. Graphical depiction of luminous intensity distribution in polar form



This diagram depicts the polar distribution of light intensity, measured in candelas. It provides information about the intensity of light, depending on the observer's orientation to the luminaire. Such polar candela plots might contain multiple distributions according to multiple planes of orientation. Many LM-79 reports include a polar representation of a luminaire's light distribution, as well as this same information in data form (below).

Source: NYSERDA, Technical Guide for Effective, Energy-Efficient Lighting

Figure 3.2d. Zonal lumen data from an LM-79 report

Zonal Lumen Summary

Zone	Lumens
0-10	357.94
10-20	1043.11
20-30	1606.62
30-40	1918.87
40-50	1951.44
50-60	1803.46
60-70	1461.26
70-80	890.06
80-90	336.42
90-100	47.01
100-110	5.87
110-120	0.00

120-130	0.00
130-140	0.00
140-150	0.00
150-160	0.00
160-170	0.00
170-180	0.00

This excerpt from an LM-79 report presents a zonal lumen summary of a luminaire, expressing the number of lumens produced within certain zones. These zones are expressed in ranges of degrees, with 0 degrees representing positioning directly beneath the light source (nadir), 90 degrees representing positioning on the same horizontal plane as the light source, and 180 degrees representing positioning directly above the light source (zenith).

Source: US DOE

3.2.2 Electrical Characteristics

The LM-79 reports on several electrical aspects of an LED product well enough to provide a basis for calculating actual energy savings. Examining electrical factors such as current (or amperage), voltage, and power draw suggest the likely the performance of a municipality's LED installation.

From an energy consumption perspective, the LM-79 contains important information relating to luminaire efficacy, and is expressed in lumens per watt. Efficacy becomes an important consideration for determining how well the cost savings provided through reduced energy demand might offset the incremental cost of an LED purchase (see the section on Economic Analysis for a more detailed discussion).

3.2.3 Color Characteristics

Aside from aesthetic considerations of the color of a light source, other reasons might exist for evaluating the color performance of an LED luminaire. If a prospective LED product is to be placed near other light sources, consistent color across the lighted space might be important to consider. Color performance might also be important, or a choice of different colors can delineate different settings (for example, residential versus commercial areas). In any case, color evaluation should be a part of any LED specifying process.

A note on uniformity

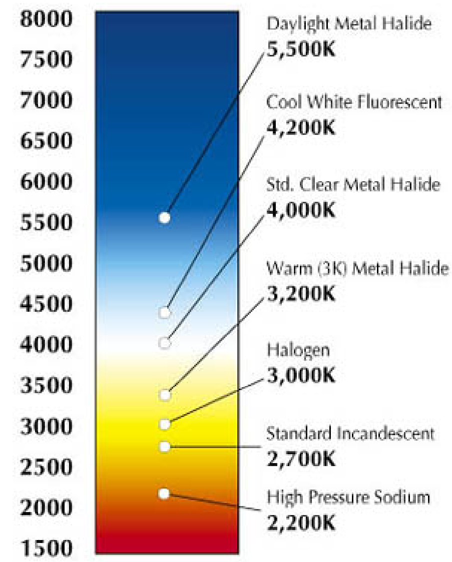
LEDs provide *directional* light by their nature, and the distribution of an LED luminaire's light is typically achieved by using an array of LEDs, with the orientation and optics of the fixture designed by manufacturers to achieve a desired light distribution. Many older lighting technologies are omni-directional, presenting problems in achieving a uniform lighting distribution. With these technologies, manufacturers must often over-design with light (that is, to meet lighting requirements at the periphery of the fixture's footprint, excess light might exist directly below the fixture).

Because a well-designed LED luminaire can produce more uniform light than omni-directional sources, it is often the case that a creditable LED alternative can light a space effectively with fewer total lumens than their incumbent counterpart. It is important not to dismiss an LED alternative that produces fewer total lumens than what a high-pressure sodium or mercury vapor lamps, for example, might produce. **The true test of a luminaire's ability to meet a lighting need lies in ensuring that light level requirements are met throughout the space, with an emphasis on providing the most uniform wash of light possible.**

The correlated color temperature (CCT) expresses the color of a light source in kelvins (K). The CCT of a source is somewhat counter-intuitive: lower color temperatures tend toward a warm golden, or reddish appearance. Higher color temperatures often exhibit cooler, bluish tendencies. The sidebar to the right shows typical color temperatures for several light sources.

In addition to conveying a luminaire's Correlated Color Temperature, an LM-79 report should also include the product's Color Rendering Index (CRI). The CRI is expressed on a scale that indicates how well the "true" colors of objects are reproduced under a light source. The CRI of a source falls between 0 and 100, with higher CRI reflecting better color rendition than lower scores. Under light sources with poor color rendering, it might be more difficult to discern the colors of clothing or automobiles. Better color rendition is preferable because it offers greater safety and security for both police and citizenry in many municipal settings. A new specification for understanding color rendition, called the Color Quality Scale (CQS) is under development.[11]

Correlated Color Temperature



Source: Mapawatt

Color temperature is measured in kelvins. This graphic shows typical color temperatures for several types of light sources. LEDs most often create white light through the combination of a blue LED and a phosphor element, which is why LEDs often tend toward higher color temperatures. Within the current generation of LEDs, warmer color temperatures are possible, but usually come at the expense of reduced efficacy.

Figure 3.2e. Color rendition among outdoor lighting technologies

Lighting Technology	Color Rendering Index (typical)
Low-Pressure Sodium (LPS)	5
Mercury Vapor	17 - 50
High-Pressure Sodium (HPS)	22
Metal Halide	65 – 80
Fluorescent / Induction	82- 90
Light-Emitting Diode (LED)	65 - 85

Source: US DOE

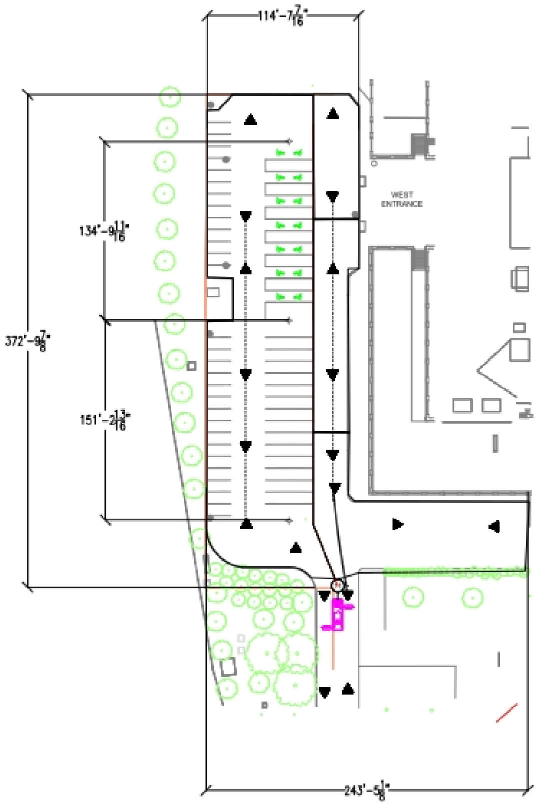
3.3 Modeling Light Readings

Photometric test data from LED luminaires can be combined with site schematic data (as a Computer-Aided Design [CAD] drawing) to model the performance of a product prior to installation. Modeling site lighting

[11] Visit http://colorqualityscale.com/ for more information.

performance is the most creditable method of determining how well a product will light a space, short of actual installation.

Figure 3.3a. Example CAD drawing of a parking lot and adjoining building



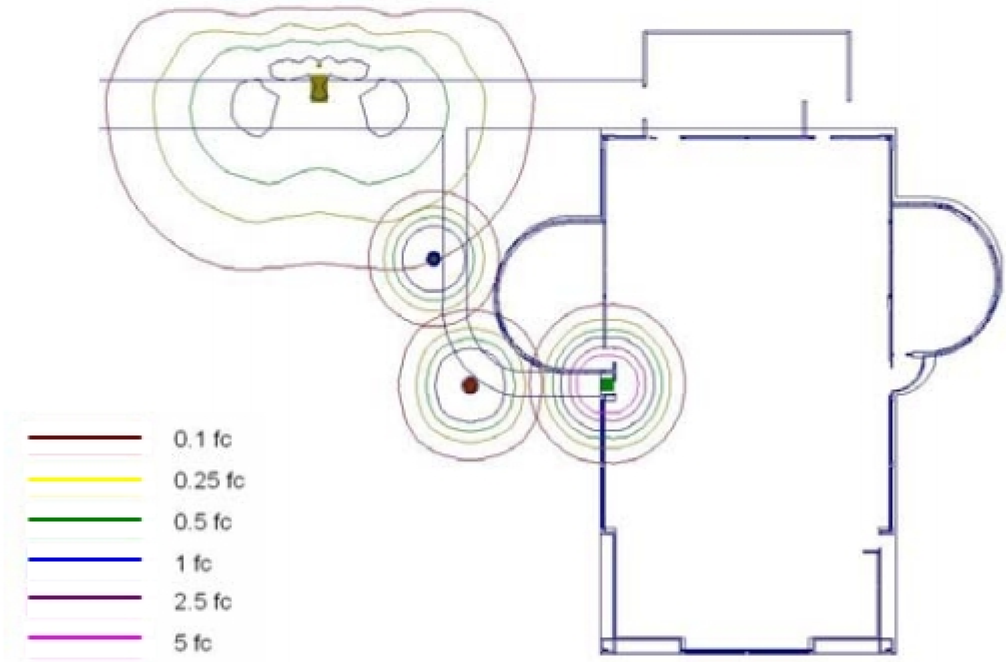
Source: The Field Museum, Chicago

A project's lighting designer or vendor can produce the computer-modeled lighting designs, provided they have photometric data[12] (that is, an LM-79 report) and accurate site drawings to work with. Numerous software packages are available for any user. Two popular applications that are independent of any manufacturer are Lighting Analyst's AGi-32 and Acuity's Visual.[13] There are also many proprietary software tools from lighting manufacturers, often tailored to handle specific brands or models of lighting equipment.

[12] The industry standard for presenting photometric data for computer modeling is a goniophotometry report in the ANSI/IES LM-63-02 format (known as LM-63). A file containing these data is commonly referred to as an "IES file" and ends with a ".ies" extension.

[13] Visit http://www.agi32.com/ and http://www.visuallightingsoftware.com/ for more information.

Figure 3.3b. Sample bird's-eye computer model of footcandle readings (parking lot)



This aerial plot provides a contour rendering of footcandle measurements at a site before the product has been installed. Other computer models might present footcandle readings at regular intervals on a grid system. The product that offers the most uniform light footprint while remaining within an acceptable range of light levels is usually the best choice.[14]

Source: Energy Systems Engineering

Although computer modeling is a good predictor of light performance, it is no substitute for evaluating lighting distribution and color performance with the naked eye. It is both prudent and appropriate to request that a vendor perform a sample installation under *in situ* (real-world) conditions. Installing a small number of luminaires might provide a greater level of confidence in a product than that achieved from evaluating test data or computer modeling.

3.4 The LM-80 Report

The main complement to the LM-79 report for testing LEDs is testing based on the IES LM-80-08 method (hereafter referred to as LM-80), which captures several additional aspects of LED performance beyond the information contained in an LM-79 report. One difference between the LM-79 and LM-80 methods is that the latter assesses LED performance over an extended period of time, and reports on how LED performance changes throughout this period. The LM-80 method also evaluates the LED itself as an isolated component, rather than testing an integrated luminaire (including optics, drivers, and other fixture components) as with the LM-79.

[14] Note that illuminance targets on site should be met not only at the time of installation, but over the entire lifetime of the installation. This is particularly relevant in the context of product lifetime, discussed in the next section.

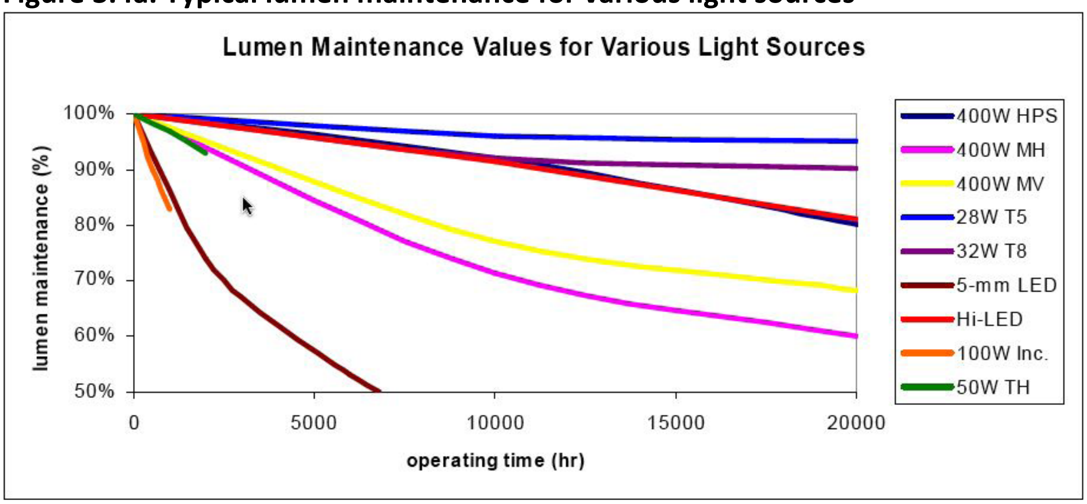
The LM-80 requires that tested LEDs be observed for at least 6,000 hours, with performance being sampled no less frequently than once every 1,000 hours. The LEDs are tested under at least three different temperatures[15] to indicate how the LED's performance varies according to ambient conditions.

3.4.1 Product Lifetime

One of the key benefits of solid-state lighting is the long lifetime of the products. Luminaires with a long life translate into deferred costs of replacement, and less frequent maintenance of light fixtures—both positive attributes in terms of cost-effectiveness and convenience. Therefore, it is important for users to understand how long they can expect their SSL luminaires to operate before needing replacement.

Often people think of a lamp "burning out" in an unmistakable fashion at the end of its life. An incandescent lamp, for example, will fail suddenly and finally, sometimes even emitting an audible pop during failure. Solid-state lighting does not offer these same clues—which has implications for appropriate maintenance of the luminaires. Instead, at a certain point they reach *passive failure*, meaning that their light output has decreased over time to a point where they are no longer considered useful. *Lumen maintenance* is the term used to describe how well a light source maintains its light output over time, and the lumen maintenance of an LED source typically follows an exponential decay curve over which light levels decrease slowly, then drop off relatively rapidly at the end of the diode's useful life. The unavoidable decrease of luminaire light output over time is referred to as *lumen depreciation*.

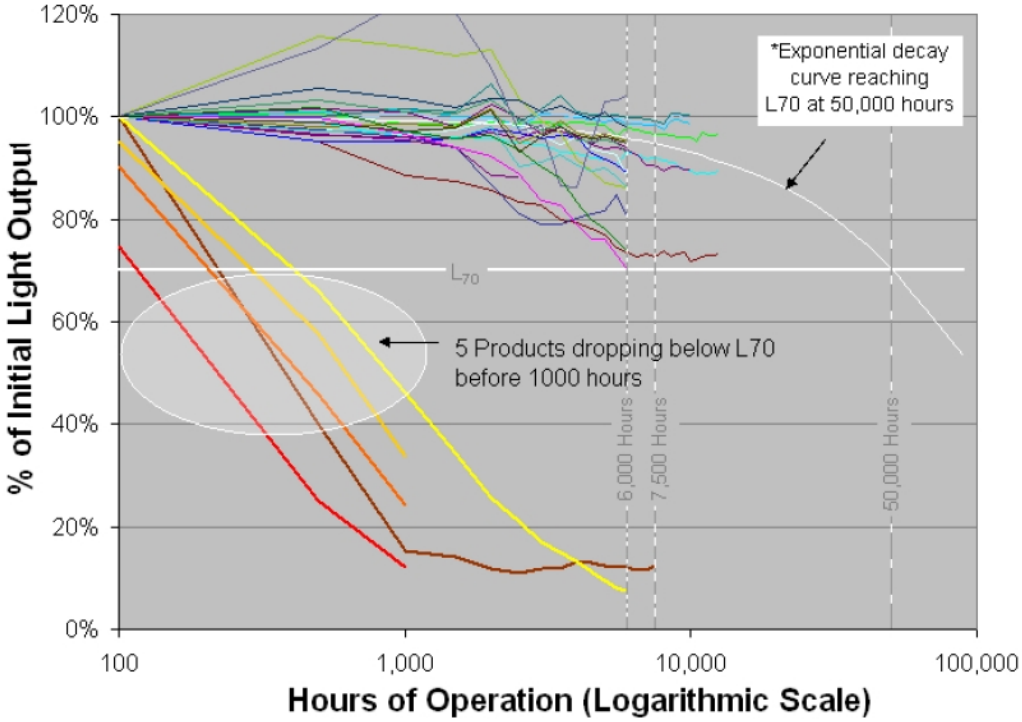
Figure 3.4a. Typical lumen maintenance for various light sources



Source: US DOE, Adapted from *Lighting Answers: LED Lighting Systems*

[15] Typically 55°C, 85°C, and another manufacturer-specified temperature

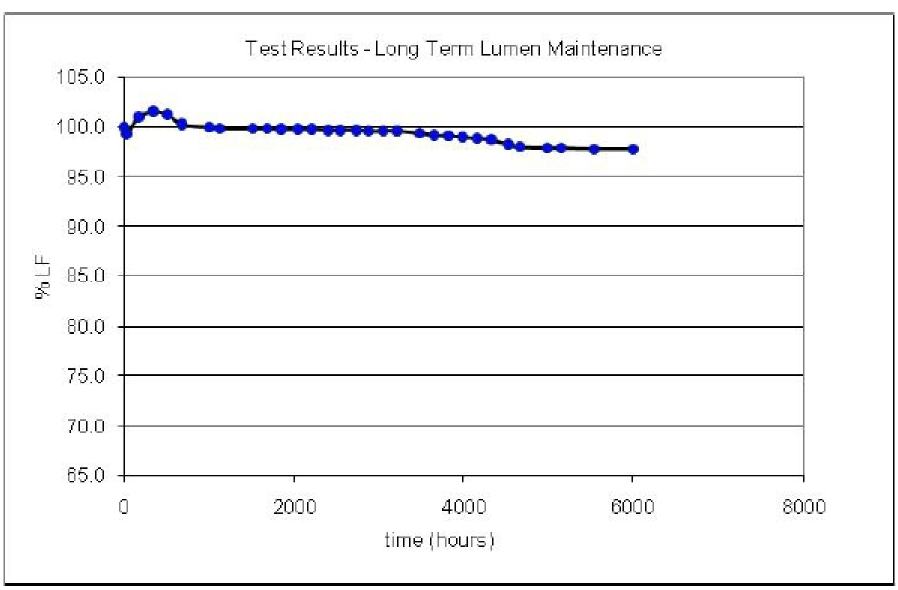
Figure 3.4b. Lumen depreciation in sampled commercial LED products



Laboratory testing is important in evaluating an LED luminaire's true life expectancy. Of the 25 LED products whose lumen maintenance data are tracked in this plot, most approximate the expected lumen depreciation curve of an LED-based light source (shown in the downward-curving white line). However, five of the products tested here failed in less than 1,000 hours of operation, and several others are approaching L70 at 10,000 hours. Investigating an LED's performance prior to installation is therefore a prudent measure.

Source: CALiPER Summary Report, Round 9, 2009

Figure 3.4c. Sample lumen maintenance data from an LM-80 report



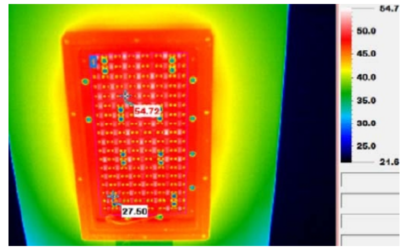
Source: Richman, Understanding IES LM-79 and IES LM-80

The industry-accepted standard for the point at which an LED luminaire has reached the end of its useful life is the point at which the source emits 70% of its initial output (or, reciprocally, the point at which the lumen output has degraded by 30%). This is often denoted as L_{70} in product literature. The Lighting Research Center has said that a 30% reduction on lumen output is "…close to the threshold for detecting gradual reductions in light output. Research shows also that reductions to 70% of initial light output are considered acceptable by the majority of occupants within a space."

Although the LM-80 does collect data on lumen maintenance over an extended period, the specification does not intend to extrapolate performance beyond the testing period. In other words, LM-80 test results can be used to track LED lumen maintenance over the test period, but should not be used to predict future performance. At best, LM-80 lumen maintenance data can demonstrate how the light output of the tested fixture is trending in a general sense along an exponential decay curve. The reliability of applying LM-80 performance to a luminaire is questionable, however, as the performance of an LED chip can vary widely, depending on the design of the luminaire in which it is situated (refer to the sidebar on the In-Situ Temperature Measurement Test).

A technical memorandum (TM-21-11) is being developed by IES to extrapolate lumen maintenance data from the LM-80 for predicting the end of life for LEDs

The In-Situ Temperature Measurement Test



Unlike the LM-79, which tests the complete luminaire, the LM-80 tests only the LED itself. This creates a challenge in evaluating thermal performance of a luminaire. The LM-80 indicates how well an LED performs under particular ambient temperatures, but that performance does not translate directly when this LED is nestled among all the other components that make up a luminaire.

The In-Situ Temperature Measurement Test (ISTMT) helps connect LM-79 and LM-80 testing with regard to thermal management. The ISTMT tests the temperature of LEDs operating within an actual luminaire. Requesting an ISTMT on an LED luminaire indicates how the LED temperatures observed within a luminaire compare to the ambient temperatures under which LM-80 testing was performed.

Source: US DOE, *Understanding & Evaluating In Situ TMP & LM-80 Reports* Webinar

3.4.2 Color Shift

The color of light tends to vary over time among most lighting technologies. This is known as color shift, and LED luminaires are no exception to this phenomenon. Significant amounts of color shift are to be avoided if possible, as this effect might result in inconsistent lighting performance among adjacent fixtures, or in lighting that does a poorer job of illuminating the space.

The LM-80 test does track color shift over the test period.[16] Selecting products with erratic or extensive color shift should be avoided in favor of those that show more consistent color temperatures over time.

[16] The LM-80 does not, however, claim to predict color shift beyond the test period.

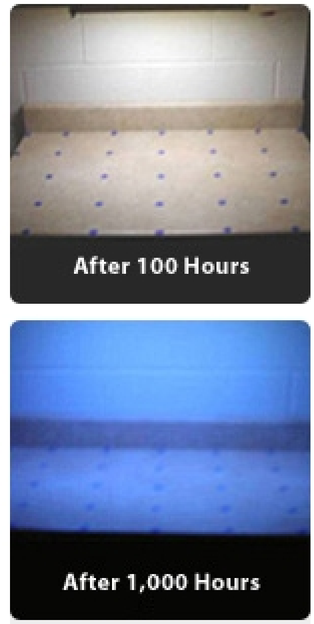
3.5 Final Considerations for the LM-79 and LM-80

Standard protocol for considering *any* LED products for general illumination should include a request for an LM-79 report conducted by a qualified, independent test laboratory,[17] and an LM-80 report from the LED manufacturer. Even if interpreting these reporting elements is not feasible, simply knowing whether a manufacturer has commissioned these reports and is willing to share them publicly says much about the manufacturer's willingness to stand behind a product.

LM-79 and LM-80 test procedures are specific to solid-state lighting technology, so it is not pertinent to ask for the same laboratory results for other lighting technologies. Many of the data contained within an LM-79 or LM-80 report, however, can be used to compare LED performance to other technologies.

It is important that laboratory conditions be consistent with site specifications and with the operating conditions of luminaires at a project site. In particular, it is important to see how well the drive current, voltage, and ambient temperature compare to the expected operating conditions for a site's installation.

LED Color Shift



Color shift is an undesired phenomenon found at noticeable levels in some lower-quality LED luminaires. The extreme case pictured above illustrates how this effect can create problems with color rendition and consistency of color over time.

Source: Norburn Lighting and Bath

4. Additional Design Considerations

Beyond examining LM-79 and LM-80 data, other project-specific considerations should be considered prior to deciding on an LED installation.

4.1 Light Loss Factors

Numerous elements might reduce the lumen output of a luminaire. These are commonly referred to as *light-loss factors*, and the environment in which luminaires operate might raise some concerns to be addressed in the product specifying process. Unavoidable light-loss factors such as lumen depreciation have already been discussed, but a site with excess pollution, dirt, or exhaust, which might accumulate on the luminaire presents additional factors that should be considered carefully.

4.2 Protection Against the Elements

In areas with high precipitation, exposure to sea water, or dusty conditions, choosing luminaires that guard against the elements will help to protect the investment in an LED product. A luminaire's Ingress Protection

[17] Visit http://www1.eere.energy.gov/buildings/ssl/test_labs.html for a listing of testing laboratories in use by the U.S. Department of Energy.

rating explains its ability to keep water or particulate matter from entering the fixture. This rating is typically denoted in an *IPXY* format, where *IP* stands for Ingress Protection, *X* is the protection rating against solids, and *Y* is the protection rating against liquids.[18] Similarly, Underwriters Laboratories have created a "Suitable for Wet Locations" designation that is useful when evaluating LED luminaires that will face rain, snow, or excessive fog.

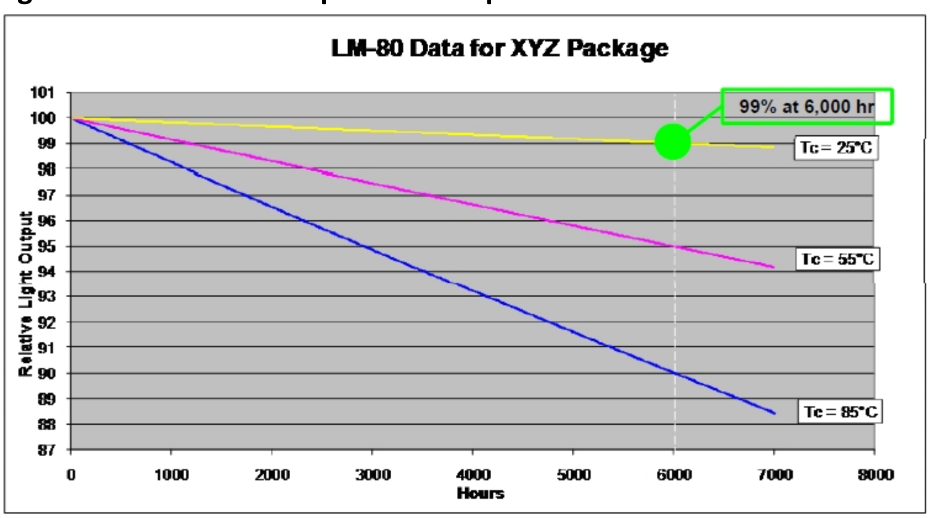
4.3 Electrical Protection

Many LED luminaires have integrated circuitry to protect against electrical surges and other electrical transients. It is important to inquire whether surge protection is integrated into the design of any luminaire under consideration. If not, inexpensive surge protection devices should be installed between the luminaire and the incoming line feed. Electrical protection, either within the luminaire itself or at the level of the external circuit, can help insure against the costly replacement of a luminaire damaged by a lightning strike or other electrical irregularities.

4.4 High Temperatures

LEDs by nature perform better at lower temperatures. LED luminaires operating in consistently high temperatures might suffer from lower efficacy, reduced light output, or a shortened product life. A well-designed LED product will have sufficient heat sinking to dissipate the heat produced by the LEDs so as to prevent overheating. The ISTMT is an excellent tool for assessing the peak operating temperature of LEDs in a luminaire. It is important in evaluating LM-80 reports to note whether the temperature condition of the lumen maintenance data compares favorably with the operating temperature observed under the ISTMT.[19]

Figure 4.4. Effect of temperature on product life



This chart illustrates how important the temperature effects surrounding LED performance are in evaluating its practical life.

Source:US DOE, *Understanding & Evaluating In Situ TMP & LM-80 Reports*

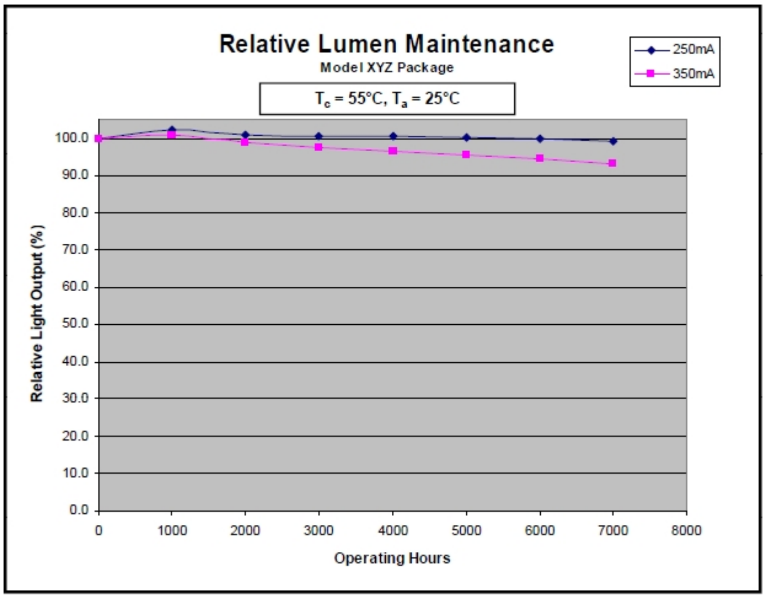
[18] For a more detailed explanation on interpreting actual Ingress Protection ratings, visit http://www.aquatext.com/tables/ip_ratings.htm

[19] The ENERGY STAR Manufacturer's Guide for Qualifying Solid State Lighting Luminaires – Version 2.1 elaborates on this topic in greater detail, and describes how to use interpolation to connect ISTMT and LM-80 results.

4.5 Drive Current

To a somewhat lesser extent than high ambient temperatures, operation of LED luminaires at higher drive currents (or amperage) will also shorten the lifespan of the luminaire, and reduce its efficacy. This phenomenon is often referred to as *LED droop*, and can have a significant effect on luminaire performance. Although a higher drive current might increase the lumen output of the luminaire, the price paid in terms of performance and lifetime makes higher drive currents something to be avoided. Often an LED product's laboratory test data will illustrate how different drive currents affect luminaire performance. An important consideration lies in comparing the intended *in situ* drive current to the lab test conditions under which the product is being evaluated.

Figure 4.5. Effect of drive current on product life



This graph of lumen depreciation for two identical LED luminaires shows how higher drive currents can accelerate lumen depreciation.

Source: US DOE

4.6 Municipal Ordinances or Guidelines

Luminaires under consideration for installation should be checked for compliance with municipal ordinances or established guidelines for municipal lighting. For example, ANSI/IES RP-8-00 is used by many municipalities as a guideline for appropriate lighting of roadways and pedestrian areas. Similarly, the IES and the International Dark-Sky Association have drafted the *Model Lighting Ordinance,* which provides guidance for creating consistent lighting standards.[20] Municipalities considering broad lighting upgrades might also want to consider upgrading or updating their lighting ordinances to improve overall lighting performance.

4.7 Backlight, Uplight, and Glare

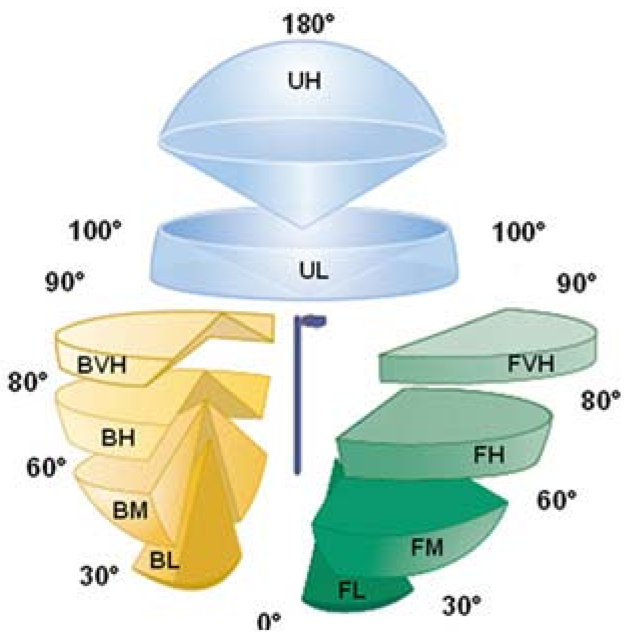
Placing light where it is intended is as important as producing an adequate amount of light for a space. Although computer modeling can help in understanding the amount of delivered light on surfaces, it does not address spillage of light into areas not intended for illumination.

[20] Draft version available at http://www.darksky.org/index.php?option=com_content&view=article&id=622.

Fortunately for outdoor lighting practitioners, a rating system exists that attempts to address this matter. The BUG (Backlight, Uplight, Glare) Rating is a metric created by IES as a way of describing light trespass, light pollution effects, and user comfort levels of a luminaire.[21] Specifically, *Backlight* refers to unwanted light spilling behind the fixture onto the area not intended to be illuminated. *Uplight* refers to light going above the horizontal plane of the fixture itself, resulting in light pollution and wasted energy consumption. *Glare* refers to high light levels at angles that cause visual discomfort or safety issues.

Each portion of the BUG Rating is described by grouping the lumen output characteristics into one of several zones based on the light levels within each of those zones. The score in each area ranges from 0 to 5, with a lower score expressing better performance in its respective part of the rating. In the BUG Rating, zones considered for each aspect of the rating, but for each element (B, U, and G) the rating assigned is the worst within the group of zones observed. The diagram below illustrates these zones, their names, and angle ranges.

Figure 4.7a. Zones evaluated for the BUG Rating



Source: IESNA TM-15-07

For each of the three facets of the BUG Rating, certain zones in the above diagram are examined.[22] Varying levels of importance may be assigned to the three elements of a product's BUG rating, depending on what design factors are important for the application, or what existing problems need to be corrected. The lower the rating for Backlight, Uplight, or Glare, the lower the light levels will be in the zones that affect each rating.

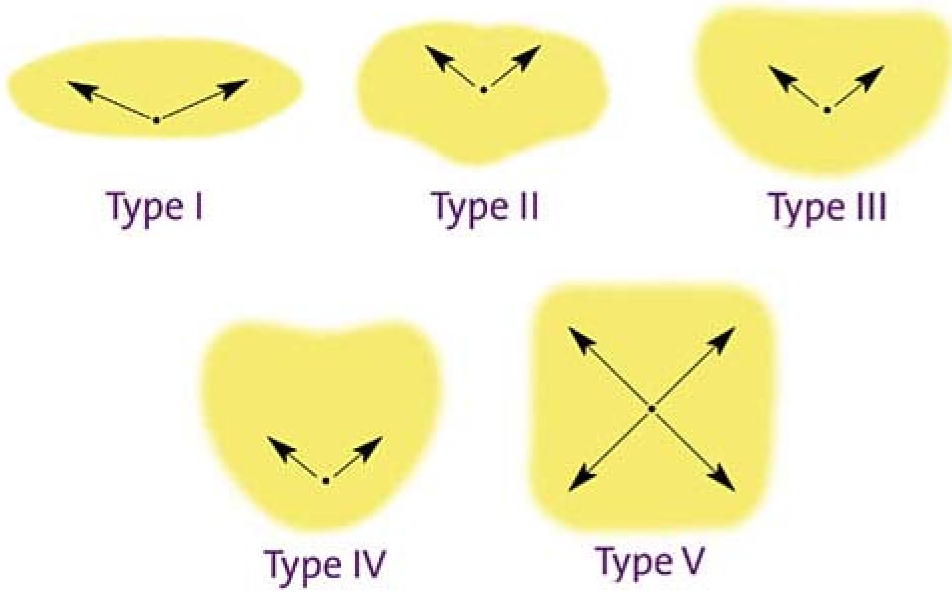
It should be noted that the BUG Rating is a relatively new metric and not yet commonplace among all vendors. Although it is preferable that an LED luminaire has an associated BUG Rating to report, a lack of this rating does not necessarily denote a poor product. In addition to a BUG Rating, additional characteristics should be considered for a more rigorous assessment:

[21] IES TM-15-07

[22] The proper way to derive each portion of the BUG Rating, as well as a useful sample case, can be found at http://www.ies.org/PDF/Erratas/TM-15-07BUGRatingsAddendum.pdf

- Lighting intensity distributions – Commonly reported on LM-79 photometric test reports, the intensity of light is presented at different mounting heights, presented on a polar graph
- Luminaire distribution types – Although variations might exist within each category, many manufacturers label their luminaires according to five common light distributions (IES RP-33). The diagram below details the approximate light footprint of each.[23]

Figure 4.7b. Types of exterior light fixtures according to aerial view of light distribution



Source: IESNA RP-33-99

- International Dark-Sky Association approved – A less rigorous assessment of light distribution than the BUG Rating, Dark-Sky compliance is assigned to luminaires that have essentially eliminated uplight spillover above the fixture's horizontal plane.
- Footcandle modeling – As discussed previously, computer software may be used to model footcandle measurements in 2-dimensional space, giving some indication of uniformity and light trespass, although these models might not say much about glare or uplight.[24]

4.8 The American Recovery and Reinvestment Act

The American Recovery and Reinvestment Act of 2009 (commonly referred to as ARRA, or the Recovery Act) is a federal effort enacted to revive the American economy through the creation of jobs and stimulation of spending. Approximately $12 billion was allocated through ARRA for energy efficiency investments. Municipalities across the country have received a portion of this funding through State Energy Programs (SEP) or Energy Efficiency and Conservation Block Grants (EECBG). These resources have made adoption of LED lighting a possibility for many municipalities for which the technology was previously out of reach. At present, more than 350 municipalities are applying ARRA funding toward the installation of LED luminaires.

[23] The Backlight aspect of the BUG rating for symmetrical fixtures such as Type V is assigned differently from asymmetrical fixtures.
[24] It is preferable to accept a computer model of light performance from a disinterested third party, rather than from a vendor or manufacturer with a financial stake in the product under evaluation.

Municipalities in receipt of ARRA funding allocated for an SSL project should take note of grant compliance requirements that might have an effect on project implementation. The ARRA grant paperwork should illustrate these requirements; and as they pertain to lighting, these mandates should be integrated into the administration of the LED project(s). Some notable aspects of ARRA that might pertain to municipal lighting projects include:

Davis-Bacon Act	Projects that have received federal funding are required to adhere to Davis-Bacon Wage Determinations, which require municipalities (and their contractors) to pay prevailing wages on all ARRA projects.[25]
Buy American Provisions	Project materials are required to be sourced within the United States in order to qualify for ARRA funding, with exceptions for certain product categories. [26]
National Historic Registration Act	It is necessary to determine whether a project involves buildings or facilities on the National Register of Historic Places, and if so, to be aware of lighting-related rules or restrictions on the historic property. The State Historic Preservation Office might be able to lend guidance on these matters.
National Environmental Protection Act	ARRA projects are held to the same National Environmental Policy Act (NEPA) requirements of any federally funded project. This means that the same process for determining Categorical Exclusions (CE) and, if necessary, Environmental Assessments (EA) and Environmental Impact Statements (EIS), must be followed.

In bidding out parts and labor for an SSL effort, it is best to inform bidders of ARRA requirements as early in the process as possible, as this knowledge might affect their project bid. The ideal approach is to illustrate ARRA compliance needs within the bid specification or Request for Proposals issued by the municipality.

4.9 Product Warranty and Reliability

A strong product warranty can act as a good insurance policy against early LED product failure. The emerging standard for outdoor LED product warranties is a minimum of three years, though five-year warranties are also common and are the obvious preference. The fine print indicates what constitutes product failure, beyond the duration of a product's warranty. LED luminaires can still be operational and yet be considered non-viable (for example, by producing unacceptable light output or through excessive color shift). It is not common for *most* LED luminaires to be designed in a modular sense; therefore, failure of individual components might warrant the replacement of the entire product.

[25] An online tool for determining prevailing wages, by county, is available at: http://www.gpo.gov/davisbacon/.
[26] A full listing of waivers issued by the U.S. Department of Energy for ARRA-funded projects is available at: http://www1.eere.energy.gov/recovery/ba_waivers.html.

The median lifetime to failure of an LED is usually designated as B_{50}. B_{50} does not refer to a catastrophic failure, but rather references the lifetime at which half of luminaires tested produce unacceptable light levels (that is, falling below L_{70}). The combination of these two metrics (B_{50} / L_{70}) is called the *Lumen Maintenance Lifetime* of a luminaire.

A final consideration in product reliability is electrical failure. This refers not to Lumen Maintenance Lifetime (failure of light output at the LED level), but rather the more traditional failure of an electronic device in which a component-level malfunction renders the product useless. With respect to LED products, this type of failure would be classified as one in which failed circuitry causes the luminaire no longer to light up.[27] Electrical failure for LED products is described using the metric F_{yy}, where *yy* denotes the percentage of luminaires that have failed (for example, F_{10} would specify the lifetime at which 10% of the tested population has exhibited an electrical failure).

An evaluation of both the B_{50} / L_{70} and F_{yy} metrics of a luminaire reasonably indicates the lifetime of an LED product in terms of both lumen maintenance, and reliability at the component level. If there aspects of product performance are not covered in typical product warranties, requirements for a project should be included within the bid specification, reassurances sought on product reliability through an assessment of the LM-79 and LM-80 reporting.

4.10 Knowing the Vendor

Just as it is essential to select a product that performs well and meets specific lighting needs, it is important to select vendors, contractors, and designers who are knowledgeable and creditable:

- Prior experience and a proven track record – Partners who have extensive experience in the lighting industry might have a better understanding of a municipality’s broader needs than do vendors who focus exclusively on specific lighting technologies.
- References – In any bidding process, it is important to consider requesting that vendors submit references from three former clients on similar LED projects.
- Impartiality – Vendors who are adamant about a particular brand or product should be avoided, as should be vendors who hesitate to answer concrete questions about products, are unwilling to consider alternative products better suited to a municipality’s needs, or are associated exclusively with a particular manufacturer.

4.11 Financial Incentives

The up-front cost of investing in more advanced, energy-efficient equipment is often higher than the cost of older, less efficient technology. Although energy-efficient devices typically make up for their higher cost through energy savings (and correspondingly, cost savings) over time, some municipalities might find themselves struggling to make such an investment, even in the short term.

Before ruling out the adoption of LED products due to “sticker shock,” municipalities might want to investigate opportunities for financial incentives on a lighting project. Financial assistance for LED upgrades might come from sources such as:

[27] This type of failure is much more likely to be covered in LED luminaire warranties than passive failure (i.e., lumen maintenance failure).

- Federal grants – ARRA has provided municipalities with the financial resources necessary to advance adoption of energy-efficient infrastructure. Hundreds of municipalities have already put forth intentions to make LED lighting a part of this effort.
- Utility incentives – Many electric utilities and energy efficiency programs or utilities offer financial incentives to customers implementing various energy-efficient products or practices, including lighting. These might take the form of prescriptive incentives for specific LED applications, or custom incentives on installed measures based on the amount of energy saved. Local electricity and efficiency providers can discuss municipalities' eligibility for incentives on LED products.
- State incentives – Statewide programs offered by State Energy Offices might help offset the cost of LED installations. State incentives also commonly fall along the lines of custom and prescriptive options.
- Tax deductions – The Environmental Protection Act of 2005 (EPAct), Section 179D, allows for tax deductions on energy efficiency improvements in buildings.[28] Most eligible deductions relate to interior lighting, although energy efficiency upgrades on parking structure lighting might also qualify.

Online resources exist that might determine which incentive opportunities are available. The Database of State Incentives for Renewable Energy (DSIRE)[29] and the American Council for an Energy-Efficient Economy[30] both maintain online resources that allow visitors to search for policy and program-level detail on energy efficiency initiatives at the state level.

4.12 Economic Analysis

Applying financial incentives to your LED project will improve its cost-effectiveness, but truly understanding the cost of an energy-efficient lighting upgrade requires a more comprehensive evaluation. A detailed economic analysis of a proposed project will provide a fuller understanding of all costs and cost savings that can be expected of the lighting installation.

Several analytical methods can help municipalities better understand the broader scope of an LED investment. For example, a simple payback analysis is one way of thinking about the return on an LED investment. A Simple Payback calculation answers the question: "About how long will it take my energy efficiency upgrade to make up for the higher initial cost through ongoing savings after the upgrade has been installed?"[31] Another analysis tool commonly used in evaluating a variety of energy efficiency investments is the life-cycle cost

[28] Specifically, the lighting system must reduce lighting power density (LPD) by certain percentages above and beyond the ASHRAE 90.1-2001 standard in order to qualify. For public buildings, the EPAct deduction may be applied to the "EPAct Designer of Record" and can be split among several companies. This deduction is scheduled to expire on December 31, 2013, although previous expiration dates have been extended in the past. For the most current information on energy-related federal tax incentives, see http://energytaxincentives.org/.

[29] http://www.dsireusa.org/

[30] http://www.aceee.org/sector/state-policy

[31] Consider the following simple example: A municipality is initially resistant to upgrading its lighting system on a municipal construction project. The total project lighting cost using the incumbent lighting product is $280,000, whereas the total cost of the more energy-efficient alternative is $685,000. The two scenarios deliver similar performance, but the municipality balks at the latter option due to the significantly higher material cost. However, a more comprehensive analysis finds that the more expensive lighting product saves the municipality $75,000 per year in other areas such as energy costs and reduced maintenance costs. Therefore, according to a simple payback analysis, the more energy-efficient installation will make up for the higher initial cost through other savings in 5.4 years ([$685,000 - $280,000] / $75,000).

analysis. This analysis attempts to factor in all costs of competing project approaches, from installation costs to disposal costs, to assess differing options more fairly.

A sample analysis that compares an incumbent outdoor lighting scenario to an alternative LED replacement is presented below:

Figure 4.12. Comparative analysis of lighting scenarios[32]

	High Pressure Sodium (HPS)	Light-emitting Diode
Rated Life	24,000 hours	100,000 hours
Initial lumens	6,300*	4,468
Average illumination levels (footcandles)	3.54	3.63
Max/Min illuminance ratio**	6.04 : 1	2.68 : 1
Correlated Color Temperature (kelvin)	1900	5000
Color Rendering Index	22	75
Input Power (watts)	97	72
Luminaire initial cost	$150.00	$725.00
Annualized maintenance cost	$39.24†	-- ††
Annual Hours of Operation	4,380	4,380
Annual Energy Consumption (kWh) per luminaire	425	311
Annual Energy Cost (at $0.103/kWh) per luminaire	$43.78	$32.03
Annual energy savings	N/A	27%
Payback period (without maintenance)	N/A	49 years
Payback period (with maintenance)	N/A	7 years

* Mean lumens were 5,500
** This metric illustrates uniformity of light; a lower ratio indicates greater uniformity
†Assumes a 5.5 year HPS lamp replacement cycle and 10-year ballast replacement cycle
†† LED products used in this study are currently anticipated to last 100,000 hours with no maintenance or luminaire replacement required

Source: Adapted from PNNL, Demonstration Assessment of Light Emitting Diode (LED) Walkway Lighting

The case above describes the retrofit of exterior walkway lighting outside a federal building, through the replacement of high-pressure sodium fixtures with an LED alternative. At first glance, it appears that the LED product costs much more because of its comparatively high price. However, this analysis factors in other elements that mitigate the incremental cost of the LED luminaires, such as reduced maintenance costs and lower electricity consumption. A comparison based on product cost alone might have suggested that a lighting retrofit would have been an economically unsound decision. However, a more comprehensive analysis suggests that the higher cost of the LED product will eventually be recouped, after which the retrofit will deliver continued savings over the rest of the product life. In the long run, this facility will save money by making the switch to LED luminaires.[33]

[32] This is a sample analysis and should not be relied on as a reference point for product price or performance, nor should a product be specified that uses this example as a standard.
[33] Note also that the LED replacement provides better uniformity and color rendition.

It is also noteworthy that, prior to installation, another LED option was considered for this project. That option delivered less light, although it still provided illuminance that met IESNA recommended minimum levels for walkways. This alternative scenario had an estimated payback period of 10 years without maintenance savings, and 3 years with maintenance savings.

The economic analysis of an LED project should incorporate both the specifics of the project, and pertinent features of the municipality. Cookie-cutter analyses or analysis tools that neglect the finer details of a project should be avoided, since they might paint an unrealistic picture of the financial implications of the installation effort.[34]

4.13 Maximizing Energy Savings

Much of the appeal to municipalities considering LED lighting lies in the prospect of reducing energy consumption, and in turn, energy costs. For a municipality considering upgrading its lighting infrastructure, it is also a good time to consider additional measures that might help to stretch energy savings opportunities. Integrating additional energy-saving systems into a lighting plan might not only reduce electricity consumption, but can also offer benefits through flexible lighting design tailored to specific municipal needs.

The most common energy-saving measure to accompany lighting upgrades is the installation of adaptive controls. This blanket term covers devices and software that can be used to squeeze additional energy savings out of lighting systems by dynamically reducing energy demand. Some of the options in the lighting design are:

- **Dimming** – Reducing the light output levels of your installed lighting product during times at which lower light levels are appropriate, or when daylight can supply a portion of the necessary light. Dimming can in some cases reduce energy consumption and extend product life.[35]
- **Bi-level operation** – Cutting light output to a set level during times of day when traffic is minimal (for example, 3:30 a.m. on a residential side street).
- **Timed operation** – Operating light sources according to a programmable timer. LEDs lend themselves well to this scheme, because of their ability to turn on and off instantly.
- **Occupancy sensors** – Installing sensors on site that monitor the area for occupancy, and dim or turn off luminaires during times of little or no occupancy.

Introducing adaptive controls will increase the material cost of an installation, but they will also contribute energy savings. An economic analysis that includes controls might demonstrate that the benefits outweigh the added cost; and in some cases controls can be implemented without extending the payback period of the installation. Of course, security and safety are of the highest priority in municipal lighting, so an evaluation of additional energy-saving enhancements should also include a consideration of whether they can be implemented without interfering with these needs.

[34] The Municipal Solid-State Street Lighting Consortium and the Clinton Climate Initiative have recently collaborated on an effort to create a web-based financial assessment tool for LED projects. Check the MSSLC website for updates.

[35] Not all LED products offer dimmability, so it is important to ensure compatibility between lighting and controls products prior to installation. Manufacturers and contractors can assist in explaining how dimming will ultimately affect a project.

Municipalities that want to reduce their utility costs further might consider adding renewable energy generation to their project sites through wind turbines or solar cells, for example. Although these advanced, integrated generation alternatives are typically very expensive, a municipality installing such measures (even as a demonstration project) can send a strong message to the community about dedication to sustainable energy alternatives.

4.14 End-of-Life Considerations

Although LEDs tend to have very long lives, it is never too early to consider how these products will be handled at the end of their useful lives. A side benefit of LED luminaires is that they do not contain mercury as do light sources such as metal halide or induction lamps, which should be recycled rather than disposed of in landfills. Nevertheless, LED luminaires contain circuitry found in most electronic devices that can contain hazardous materials such as lead and cadmium. Therefore, an LED fixture should be recycled according to appropriate e-waste policies at its life's end. If a municipality already offers e-waste recycling through existing waste management operations, it is important for the municipality to ensure that spent LED luminaires are handled properly. E-waste recycling, if absent, should be considered in municipal planning; partnerships with retailers, manufacturers, or recycling contractors should also be explored.[36]

Another consideration beyond deciding how to handle expired LED fixtures is how to determine when these fixtures have reached the end of their useful lives. Recall that LEDs do not fail catastrophically, but rather grow dimmer over time to the point at which they are no longer able to produce an acceptable amount of light. Again, an LED's end of life is typically described as the point at which the fixture emits 70% of its original light output.

How does one determine when an LED luminaire has reached this point? Identifying a "dead" LED luminaire by sight is difficult, if not impossible. The human eye cannot discern small (or even moderate) differences in light output, and due to the very gradual decline in light output over time, it is difficult to notice when an LED has crossed the threshold from "viable" to "expired."[37]

If the rated life of a luminaire is creditable (and again, LM-80 reporting should be trusted over unverified claims by a manufacturer), it is highly recommended to track the annual hours of operation of the luminaires, anticipating the end of their rated life according to annual usage, and replacing those luminaires accordingly. LED luminaires might have a life well in excess of ten years, so implementing appropriate tracking measures for this task is important. The long life of an LED product necessitates procedures for maintaining institutional knowledge of luminaires.

The most reliable method for determining whether luminaires are still viable is to perform periodic lighting measurements to ensure that appropriate light levels are being maintained. This requires lighting expertise and can be costly to implement, however. Unfortunately, it is beyond the capabilities of many municipalities to implement.

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[36] An ARRA grant application might have asked for an articulated waste stream plan. If so, a disposal plan should include how expired LED luminaires fit into it.

[37] The lighting industry is currently investigating methods of addressing this need. For example, some manufacturers of adaptive controls are beginning to implement photo sensors into control systems, allowing light levels of individual luminaires to be observed remotely. Solutions such as this simplify monitoring of lumen maintenance, but they also introduce additional costs.

5. Additional Resources

The U.S. Department of Energy has dedicated several programs solely to assist municipalities and other entities that are interested in adopting solid-state lighting:

DOE Technical Assistance Center
https://tac.eecleanenergy.org/
A portal for recipients of State Energy Program or Energy Efficiency and Conservation Block Grant funding to make direct requests for technical assistance with the specifics of their projects.

DOE Solution Center
http://www1.eere.energy.gov/wip/solutioncenter/default.html
A repository of technical assistance resources for Energy Efficiency and Conservation Block Grant Program and State Energy Program grantees, covering topics such as lighting.

DOE Municipal Solid-State Street Lighting Consortium
http://www1.eere.energy.gov/buildings/ssl/consortium.html
A group open to municipalities seeking information and resources for integrating SSL into their street lighting applications.

GATEWAY Demonstrations
http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html
DOE supports promoting real-world SSL results through the GATEWAY program, which produces detailed case studies of SSL projects.

CALiPER Program
http://www1.eere.energy.gov/buildings/ssl/caliper.html
CALiPER performs independent laboratory testing of commercially available LED products and presents the results in regular reporting on both the specific products covered in each round of testing, as well as more general assessments of how SSL products are evolving over time.

Commercial Building Energy Alliance (CBEA)
http://www1.eere.energy.gov/buildings/alliances/technologies.html
The CBEA has developed information on SSL, including lighting specifications for two applications common to many municipalities:

LED Site (Parking Lot) Lighting

Performance specification for efficient design of LED lighting systems for parking lot applications. The specification is appropriate for application to a specific site, rather than to a specific product and provides information about both the luminaire and how the site should be lighted.

High Efficiency Parking Structure Lighting

Performance specification for high-efficiency fluorescent, induction, and LED lighting in parking structures. The specification provides for efficient design in parking structure applications and includes recommendations for the use of lighting controls.

Next Generation Luminaires
http://www.ngldc.org/
An annual competition awarding best-in-class designations to the top products in commercial and municipal applications.

DOE SSL Fact Sheets
http://www1.eere.energy.gov/buildings/ssl/factsheets.html
Brief, accessible informational documents covering a wide variety of SSL topics

Lighting Facts
http://www.lightingfacts.com/
A packaging label, similar to the Nutrition Facts Label found on food packaging, to tell consumers what performance to expect from a lighting product (light output, efficacy, color, etc.)

TINSSL
http://www1.eere.energy.gov/buildings/ssl/technetwork.html
The Technical Information Network for Solid-State Lighting provides its members with opportunities to receive updates on SSL technologies, best practices, R&D innovations, etc.

LED Products Qualification
Designations and specifications on LED products can provide shortcuts for identifying high-quality products:

ENERGY STAR
http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
The ENERGY STAR program creates and revises specifications for evaluating energy-efficient products on both quality and performance, and maintains listings of products (lighting and otherwise) that have passed the rigors of testing.

DesignLights™ Consortium (DLC) Qualified Products List (QPL)
http://www.designlights.org/solidstate.about.php
A list of commercial SSL qualified products, covering many luminaire categories not presently covered by ENERGY STAR.

Underwriters Laboratories
http://www.ul.com/
A nonprofit organization focused primarily on safety standards for many technologies, including lighting (for example, UL 8750, the Standard for Safety of Light Emitting Diode (LED) Equipment for Use in Lighting Products).

Illuminating Engineering Society of North America
http://www.iesna.org/
A reputable nationwide organization that provides design recommendations and test methods for a broad spectrum of lighting products.

6. Glossary of Lighting Terminology

Ambient temperature
The temperature of the air surrounding a luminaire.

Backlight
Light cast by a luminaire in a backward direction relative to the forward orientation of the source. In luminaires intending to throw forward light, backlight might contribute to light trespass.

Candela
SI unit of measurement describing a light source's luminous intensity, in a specific direction.

Color rendering index (CRI)
Measurement describing a light source's ability to render the "true" color of objects, on a scale of 0 to 100. Higher CRI indicates better color rendition.

Color shift
The amount by which a light source's correlated color temperature changes over time.

Correlated color temperature (CCT)
The color reference of light produced by a source, measured in degrees kelvin. The CCT relates how "cool" or "warm" the light appears to the eye. Commonly abbreviated to "color temperature."

Current
The rate of flow of electricity, expressed in amperes.

Drive current
The amperage used to operate a luminaire (see also *Current*).

Efficacy
See *luminous efficacy*.

Energy
A description of the power consumed by a light source over time, commonly expressed in kilowatt-hours (kWh).

Footcandle (fc)
A measurement expressing luminance on a surface, equal to one lumen per square foot.

Glare
A negative lighting effect that might cause discomfort or disability for users, due to high illuminance levels.

Illuminance
An expression of the amount of light falling upon a surface, typically expressed in footcandles.

In situ
Latin phrase meaning “in position”; in lighting parlance, a reference to luminaires installed on site.

Life-cycle cost analysis
A comprehensive economic analysis that takes into account all of the relevant project costs over its lifetime, including material, maintenance, and disposal costs.

Light-emitting diode
A semiconducting electronic device that emits light when a current is passed through it.

Light loss factors
A blanket term describing various phenomena that might reduce the light output of a luminaire.

Light trespass
A negative performance phenomenon of a light source, in which light is cast where it is not wanted.

Lumen
A unit measurement of the rate at which a lamp produces light. A lamp's lumen output rating expresses the total amount of light the lamp emits in all directions per unit of time.

Lumen depreciation
A phenomenon common to all artificial light sources in which the amount of light produced by the source decreases over time.

Lumen maintenance
The ability of a light source to maintain its light levels over time.

Luminaire
A self-contained light source with all the necessary components for operation, requiring only an external electrical source to function.

Luminous efficacy
A measurement of a light source’s efficiency in producing light from electricity, expressed in lumens per watt (LPW).

Nadir
The angle pointing directly downward from a luminaire.

Passive failure
Failure of a luminaire in which the light source still functions, but no longer delivers an acceptable amount of light.

Payback period
The amount of time in which the higher initial investment in a lighting installation is recovered through other cost savings, such as energy or maintenance costs.

Power
A measure of the rate at which energy is consumed, expressed in watts.

Solid-state lighting
A term describing light sources that rely on light-emitting diodes to produce light.

Uniformity
The degree of variation in illuminance over a lighted surface. Uniformity is typically expressed as either the ratio of minimum to maximum illuminance, or minimum to average illuminance.

Uplight
Light emitted upward at greater than 90° from a luminaire's nadir. Uplight might come from the light source itself, or from reflected light.

Voltage
A measure of electrical potential, expressed in volts.

Zenith
The angle pointing directly upward from a luminaire, 180° from the nadir.

Sources: Illuminating Engineering Society, Merriam-Webster, National Lighting Product Information Program

7. Reference List

Bullough, J. *Lighting Answers: LED Lighting Systems*. Troy, NY: National Lighting Product Information Program, Lighting Research Center, Rensselaer Polytechnic Institute, 2003.

Bullough, J. et al., *ASSIST recommends… LED Life for General Lighting: Definition of Life*, Volume 1, Issue 1. Troy, NY: Lighting Research Center, Rensselaer Polytechnic Institute, February 2005.

ENERGY STAR®. *ENERGY STAR® Manufacturer's Guide for Qualifying Solid-State Lighting Luminaires – Version 2.1*. April, 2010. Retrieved from http://www.energystar.gov/ia/partners/manuf_res/downloads/ENERGYSTAR_Manufacturers_Guide_v2.1.pdf

Gordon, Kelly, & Jason Tuenge. *Understanding & Evaluating LM-79 Reports*. U.S. Department of Energy and Northeast Energy Efficiency Partnerships. Webinar presentation made to the Technical Information Network for Solid-State Lighting. August 10, 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/test-reports-webcast_presentation1.pdf

Gordon, Kelly, & Jason Tuenge. *Understanding & Evaluating In Situ TMP & LM-80 Reports*. U.S. Department of Energy and Northeast Energy Efficiency Partnerships. Webinar presentation made to the Technical Information Network for Solid-State Lighting. August 11, 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/test-reports-webcast_presentation2.pdf

Gordon, Kelly, & Jason Tuenge. *Walking Through Examples of Real LM-79 & LM-80 Reports*. U.S. Department of Energy and Northeast Energy Efficiency Partnerships. Webinar presentation made to the Technical Information Network for Solid-State Lighting. August 12, 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/test-reports-webcast_presentation3.pdf

Gu, Y., N. Narendran, and J.P. Freyssinier. 2004. *White LED performance*. Fourth International Conference on Solid State Lighting, Proceedings of SPIE 5530, eds. I.T. Ferguson, N. Narendran, S.P. DenBaars, J.C. Carrano, 119-124. Bellingham, Wash.: International Society of Optical Engineers.

Illuminating Engineering Society of North America. *Addendum A for IESNA TM-15-07: Backlight, Uplight, and Glare (BUG) Ratings*. Retrieved from http://www.ies.org/PDF/Erratas/TM-15-07BUGRatingsAddendum.pdf

Illuminating Engineering Society of North America. *American National Standard Practice for Roadway Lighting*. ANSI/IES RP-8-00 (R2005). July, 2000.

Illuminating Engineering Society of North America. *IES Seminar: Lighting Economics***.** SEM-3-09. 2009.

Illuminating Engineering Society of North America. *Lighting for Exterior Environments*. IES RP-33-99. February, 1999.

Illuminating Engineering Society of North America. The Lighting Handbook, 9th Ed. 2000.

International Dark-Sky Association (IDA) and the Illuminating Engineering Society of North America (IESNA) Joint Task Force. *Model Lighting Ordinance, Draft 2*. June 23, 2010. Retrieved from http://docs.darksky.org/MLO/2010/MLOdraft19July.pdf

Kauffman, Rick. *Calculating Light Loss Factors (LLF) in the LED World*. Presentation made to the Municipal Solid-State Street Lighting Consortium (MSSLC). March 8, 2011. Kansas City, Missouri.

Lighting Research Center, Rensselaer Polytechnic Institute. *New York Energy $mart[SM] Small Commercial Lighting Program Technical Guide for Effective, Energy-Efficient Lighting*. Retrieved from http://www.nyserda.org/sclp2/pdf/SCLP%20Technical%20Guide%20-%20Entire%20Document%2001-10-07.pdf

National Electrical Manufacturers Association. *ANSI/IEC 60529-2004, Degrees of Protection Provided by Enclosures*. November 3, 2004. Retrieved from http://www.nema.org/stds/complimentary-docs/upload/ANSI_IEC%2060529.pdf

Next Generation Lighting Industry Alliance with the U.S. Department of Energy. *Next Generation Lighting Industry Alliance with the U.S. Department of Energy, First Edition*. May, 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_luminaire-lifetime-guide.pdf

Next Generation Lighting Industry Alliance with the U.S. Department of Energy. *Reporting LED Luminaire Product Performance: An Initiative for Better Solid-State Lighting*. December, 2008. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_productperformanceguide.pdf

Pacific Northwest National Laboratories. *Demonstration Assessment of Light Emitting Diode (LED) Walkway Lighting*. March, 2008. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_faa.pdf

Richman, Eric. *Understanding IES LM-79 & IES LM-80*. Presentation made at Lightfair International 2009. May 5-7, 2009. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lightfair8_richman-ies.pdf

Tuenge, Jason. *MSSLC Model Specification for LED Roadway Lighting*. Presentation made to the Municipal Solid-State Street Lighting Consortium (MSSLC). March 9, 2011. Kansas City, Missouri.

United States Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE). *LED Measurement Series: LED Luminaire Reliability*. PNNL-SA-61137. October 2009. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/Luminaire_Reliability.pdf

United States Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE). *Solid-State Lighting Research and Development: Multi-Year Program Plan*. March 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2010_web.pdf.

Welsh, Fred. *LED Luminaire Lifetime*. Presentation made at U.S. DOE SSL Market Introduction Workshop 2010. July 21, 2010. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/welsh_ledlum_philly2010.pdf